7634 *J. Am. Chem. Soc.* **1996,** *118,* 7634−7635

Ynolates from the Reaction of Lithiosilyldiazomethane with Carbon Monoxide. New Ketenylation Reactions

Hidetomo Kai, Keiji Iwamoto, Naoto Chatani, and
Shinji Murai*

*Department of Applied Chemistry, Faculty of Engineering
Osaka University, Suita, Osaka 565, Japan*

Received April 15, 1996

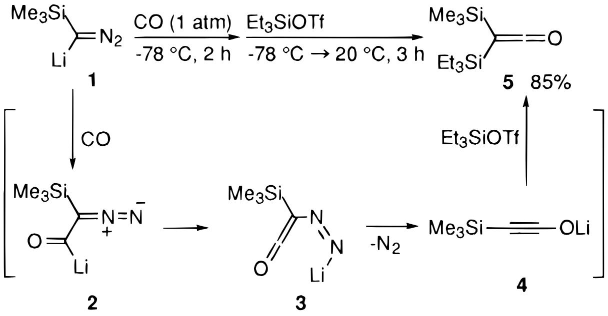
Ynolates are the triple-bond version of enolates. In contrast to the well-established chemistry of enolates,[1] only scattered examples of the ynolate chemistry have been reported so far.[2−6] The first example was reported in 1975 by Schöllkopf, who succeeded in the generation of lithium phenylethynolate by extrusion of benzonitrile from 5-lithio-3,4-diphenylisoxazole.[2] Since then, various routes to ynolates have been developed by Kowalski,[3] Stang,[4] Julia,[5] and Rathke.[6] Nevertheless, ynolates received only little attention as synthetic reagents because of lack of convenient methods of their generation. The reactions of ethynolates with aldehydes,[2a,b,3a] ketones,[2a,b,3a] and imines[2c] to give the corresponding β-lactones or β-lactams have been studied. A silylethynolate[6] is quite attractive because a silyl group can be converted into other functional groups in various ways.[7] In this paper a unique access to and the new reactions of the silylethynolate will be described.

$-C\equiv C-O-Li$ (ynolates) $\quad >C=C(-)-O-Li$ (enolates)

Our new route to the lithium silylethynolate involves the acyllithium (R−CO−Li) chemistry. Two different approaches have been developed to utilize the highly reactive intermediate RCOLi. The one involves in situ intermolecular trapping of the acyllithium as studied by Seyferth[8] and others.[9] The other developed by us involves intramolecular conversion of the unstable acyllithium to a more stable but still useful intermediate such as enolate.[10] Now we have studied the reaction of a lithiated silyldiazomethane **1** with carbon monoxide expecting that the extrusion of dinitrogen from an acyllithium **2** should provide the driving force for a clean reaction. This is the case. The results not only provide a unique entry to a lithium ynolate having a silyl group[6] **4** (Scheme 1) but also lead to a unique synthetic operation that enables “ketenylation”.[11]

To a THF−hexane solution of trimethylsilyldiazomethane[12] was added a hexane solution of BuLi (1.2 equiv) at −78 °C and the mixture was stirred at that same temperature for 1 h. Then, the mixture was exposed to an atmospheric pressure of carbon monoxide at −78 °C for 2 h. Addition of 1.1 equiv of triethylsilyl trifluoromethanesulfonate (-78 °C then 20 °C for 3 h) and workup with aqueous saturated NH$_4$Cl gave triethylsilyl(trimethylsilyl)ketene **5**[13] as the sole product in 85% yield after column chromatography on silica gel. Similarly the use of ^{i}Pr$_3$SiCl (62%), ^{t}BuMe$_2$SiOTf (76%),[6b] Me$_3$GeBr (43%),[14] and Bu$_3$SnCl (85%)[15] in place of Et$_3$SiOTf gave the corresponding silylketenes, respectively. In all cases, *O*-trapping[3f,j,4,5,16] was not observed. As shown in Scheme 1, the acyllithium **2** should be the primary intermediate of the reaction of **1** with carbon monoxide.[17] Silylynolate **4** would be formed via **3** (there are some alternative possibilities).

Scheme 1



The use of **4** as a synthetic intermediate has been a challenge. All attempts for quenching silylethynolate **4** with carbon electrophiles such as methyl iodide, benzyl bromide, and benzaldehyde[18] were unsuccessful, which were in accordance with a previous study.[6] However, we were pleased to observe that the addition of Me$_3$Al promoted the reaction of silylethynolate **4** with oxiranes leading to lactones (eq 1). The results constitute a unique transformation, i.e., nucleophilic ketenylation. To a THF solution of **4** was added a hexane solution of Me$_3$Al (1.1 equiv) at −78 °C and the reaction mixture was stirred at 0 °C for 1 h. Then, addition of cyclohexene oxide at −78 °C, stirring at 20 °C for 12 h, and workup gave lactone **6**

---

(1) *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 2, pp 99−319.

(2) (a) Schöllkopf, U.; Hoppe, I. *Angew. Chem., Int. Ed. Engl.* **1975**, *14*, 765. (b) Hoppe, I.; Schöllkopf, U. *Liebigs Ann. Chem.* **1979**, 219. (c) Adlington, R. M.; Barrett, A. G. M.; Quayle, P.; Walker, A.; Bettz, M. J. *J. Chem. Soc., Chem. Commun.* **1981**, 404.

(3) (a) Kowalski, C. J.; Fields, K. W. *J. Am. Chem. Soc.* **1982**, *104*, 323. (b) Kowalski, C. J.; Haque, M. S.; Fields, K. W. *J. Am. Chem. Soc.* **1985**, *107*, 1429. (c) Kowalski, C. J.; Haque, M. S. *J. Org. Chem.* **1985**, *50*, 5140. (d) Kowalski, C. J.; Haque, M. S. *J. Am. Chem. Soc.* **1986**, *108*, 1325. (e) Kowalski, C. J.; Lal, G. S. *J. Am. Chem. Soc.* **1986**, *108*, 5356. (f) Kowalski, C. J.; Haque, M. S.; Lal, G. S. *J. Am. Chem. Soc.* **1986**, *108*, 7128. (g) Kowalski, C. J.; Lal, G. S. *Tetrahedron Lett.* **1987**, *28*, 2463. (h) Kowalski, C. J.; Reddy, R. E. *J. Org. Chem.* **1992**, *57*, 7194. (i) Reddy, R. E.; Kowalski, C. J. *Org. Synth.* **1993**, *71*, 146. (j) Zhdankin, V. V.; Stang, P. J. *Tetrahedron Lett.* **1993**, *34*, 1461.

(4) Stang, P. J.; Roberts, K. A. *J. Am. Chem. Soc.* **1986**, *108*, 7125.

(5) Julia, M.; Saint-Jalmes, V. P.; Verpeaux, J. N. *Synlett* **1993**, 233.

(6) Silylethynolates by deprotonation of silylketenes. (a) Woodburgy, R. P.; Long, N. L.; Rathke, M. W. *J. Org. Chem.* **1978**, *43*, 376. (b) Kita, Y.; Tsutsumi, Y.; Kitagaki, S. *Chem. Pharm. Bull.* **1992**, *42*, 233. (c) By desilylation of bissilylketene, see: Ito, M.; Shirakawa, E.; Takaya, H. *Abstract of the 70th Annual Meeting of the Chemical Society of Japan*, Tokyo; March 1996, 2J392.

(7) (a) Weber, W. P. *Sillicon Reagents for Organic Synthesis*; Springer-Verlag: Berlin, 1983. (b) Colvin, E. W. *Sillicon in Organic Synthesis*; R. E. Krieger Press: Florida, 1985.

(8) (a) For representative examples, see: Seyferth, D.; Weinstein, R. M. *J. Am. Chem. Soc.* **1982**, *104*, 5534. (b) Seyferth, D.; Hui, R. C.; Wang, W.-L.; Archer, C. M. *J. Org. Chem.* **1993**, *58*, 5843 and references cited therein.

(9) (a) Nudelman, N. S.; Doctorovich, F. *Tetrahedron* **1994**, *50*, 4651. (b) Li, N.-S.; Yu, S.; Kabalka, G. W. *J. Org. Chem.* **1995**, *60*, 5973.

(10) (a) Murai, S.; Ryu, I.; Iriguchi, J.; Sonoda, N. *J. Am. Chem. Soc.* **1984**, *106*, 2440. (b) Ryu, I.; Hayama, Y.; Hirai, A.; Sonoda, N.; Orita, A.; Ohe, K.; Murai, S. *J. Am. Chem. Soc.* **1990**, *112*, 7601. (c) Orita, A.; Fukudome, M.; Ohe, K.; Murai, S. *J. Org. Chem.* **1994**, *59*, 477. (d) Orita, A.; Ohe, K.; Murai, S. *Organometallics* **1994**, *13*, 1533.

(11) Only scattered examples of ketenylation (a reaction that enables the nucleophilic introduction of a ketenyl unit into an organo molecule) have been known, see refs 2−6.

(12) Shioiri, T.; Aoyama, T.; Mori, S. *Org. Synth.* **1990**, *68*, 1. A 2.0 M hexane solution of trimethylsilyldiazomethane is commercially available, purchased from Aldrich Chemical Co.

(13) All new compounds were characterized by NMR, IR, mass spectral data, and elemental analyses or high-resolution mass spectra. See the supporting information.

(14) Nikolaeva, S. N.; Zolotareva, A. S.; Ponomarev, S. V.; Petrosyan, V. S. *Izv. Akad. Nauk Ser. Khim.* **1994**, 911; *Chem. Abstr.* **1994**, *122*, 160751.

(15) Inoue, S.; Sato, Y.; Suzuki, T. *Organometallics* **1988**, *7*, 739.

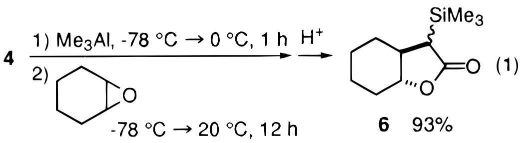
(16) Groh, B. J.; Magrum, G. R.; Barton, T. J. *J. Am. Chem. Soc.* **1987**, *109*, 7568.

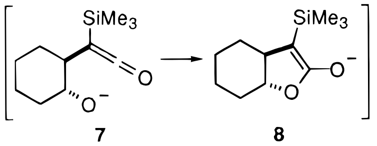
(17) Related reactions with transition metals have been reported: (a) Rüchardt, C.; Schrauzer, G. N. *Chem. Ber.* **1960**, *93*, 1840. (b) Deydier, E.; Menu, M.-J.; Dartiguenave, M.; Dartiguenave, Y. *J. Organomet. Chem.* **1993**, *458*, 255.

(18) When benzaldehyde (−78 °C, 1 h) was used as an electrophile in the presence of Me$_3$Al, many products including β-lactones were obtained.

S0002-7863(96)01229-2 CCC: $12.00

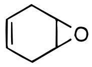
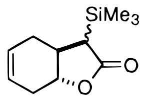
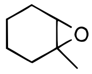
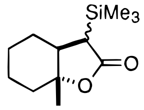
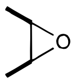
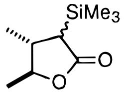
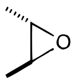
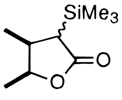
in 93% yield. The stereochemistry at the ring junctions was complete (trans) with the 89:11[19] diastereomeric ratio at the α-position to the carbonyl group. The reaction proceeded via ring-opening ketenylation of cyclohexene oxide with silylynolate **4** followed by intramolecular cyclization (**7** → **8**). A workup using a bulky proton source such as 2,6-di-*tert*-butylphenol improved the α-position selectivity to 96:4.[19]





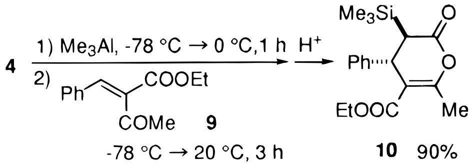
The use of Et$_2$AlCl (44%) or Et$_2$AlOEt (44%) instead of Me$_3$Al also gave **6** but in lower yields. In the absence of Me$_3$Al, only trace amounts of **6** were formed. There are two possibilities for the role of Me$_3$Al: (i) Me$_3$Al acts as a Lewis acid to activate cyclohexene oxide[20] and (ii) Me$_3$Al forms an ate complex with ynolate **4**.[21] NMR study has suggested the latter more likely.[22] The results of the reaction with several oxiranes are summarized in Table 1. The reaction is highly regioselective (entry 2) and highly stereospecific (entries 3 and 4).

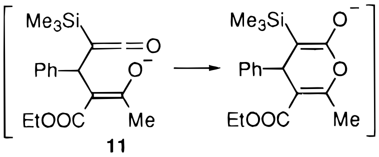
Table 1. Reactions of Ynolate **4** with Oxiranes

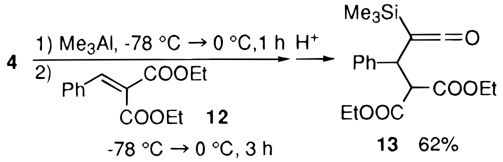
entry	oxirane	product [a]	yield [b]
1			72% [c]
2			75% [d]
3			72% [e]
4			71% [f]

[a] In all cases, ring-opening proceeded in a trans manner. [b] Isolated yield. [c] Diastereomeric ratio at α to the carbonyl position determined by GC was 90:10. [d] 62:38. [e] 85:15. [f] 81:19.

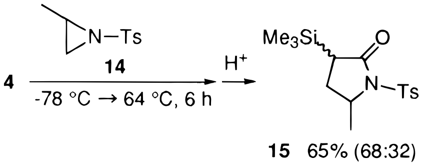
While the reaction of **4** with α,*β*-unsaturated carbonyl compounds such as methyl vinyl ketone and methyl acrylate in the presence of Me$_3$Al was not successful, treatment of ynolate **4** with ethyl benzalacetoacetate **(9)** (1.0 equiv) in the presence of Me$_3$Al (1.1 equiv) gave six-membered lactone **10** as a single diastereomer in 90% overall yield from silyldiazomethane. This reaction would involve 1,4-addition of **4** to **9** leading to **11** followed by cyclization. Interestingly and suprisingly, the reaction using diethyl benzalmalonate **(12)** (1.0 equiv) gave only ketene **13** in 62% isolated yield after column chromatography on silica gel and no cyclization product was obtained. This result suggests that reaction of **4** with carbon electrophiles proceeds via ketenylation.[23]



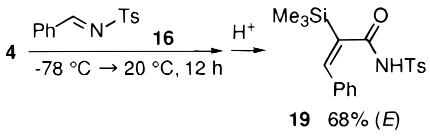


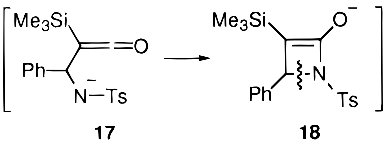


The ketenylation reaction using thus generated ynolate **4** can also be applied to nitrogen-containing carbon electrophiles, in which case the addition of Me$_3$Al is not neccesary.[24] Propylenimine **14** (used in 1.1 equiv) underwent regioselective ring opening and recyclization (in a similar manner as shown in eq 1) to give a five membered lactam **15**.



The ynolate **4** reacted with an aldimine **16** through initial addition to give **17**, cyclization affording **18**, and then ring opening leading to **19** in 68% isolated yield.





Further extention of this unique opportunity of "ketenylation" is in progress.

Acknowledgment. This work is partially supported by grants from the Ministy of Education, Science, Sports and Culture, Japan.

Supporting Information Available: Typical experimental procedure and spectral data of products (10 pages). See any current masthead page for ordering and Internet access instructions.

JA961229A

---

(19) With cis predominating although not fully established.

(20) Fukumasa, M.; Furuhashi, K.; Umezawa, J.; Takahashi, O.; Hirai, T. *Tetrahedron Lett.* **1991**, *32*, 1059.

(21) (a) Boireau, G.; Abenhaim, D.; Bernardon, C.; Henry-Basch, E.; Sabourault, B. *Tetrahedron Lett.* **1975**, 2521. (b) Zweifel, G.; Miller, J. A. *Org. React.* **1984**, *32*, 375.

(22) Before and after the addition of Me$_3$Al to silylynolate **4**, ^{1}H-NMR chemical shifts for methyl groups changed for silylynolate from δ −0.12 to δ −0.05 and for Me$_3$Al from δ −1.00 to δ −1.12 (0 °C in 10% THF-d_8). In contrast, the changes were negligible for the cyclohexene oxide/Me$_3$Al mixture.

(23) A [2 + 4] or [2 + 2] cycloaddition cannot be ruled out in the reaction of **4** with α,*β*-unsaturated carbonyl compounds or imines.

(24) Nitrogen atoms can abstract Li$^+$ from **4** without any assistance.